Control of Snow and Ice on Road and Communication Facilities in the Himalayas

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Introduction

India, with its vast Himalayan mountains in the north has its share of snow hazards and connected problems. The unnegotiable and formidable vast Himalayas carry within them a hidden treasure of natural resources. Their forests are rich, the soil contains precious minerals, and the blanket of snow ensures the supply of sweet water. The Indian Himalayas are sparsely populated with concentrations along the river waterways and their valleys. To tap these resources and to keep pace with the increase of population and growth of industry, it is imperative that the road communication system should remain open throughout the year. This task involves the study of Indian snow and ice conditions, along with terrain and weather patterns, and the evolution of effective methods to keep the traffic moving even in the severest of winters. This is a challenging problem for the engineers.

In this paper an effort has been made to spell out the problems as related to Indian snow conditions and to cost-effective methods of snow and ice control with a view to keep the roads/tracks open for traffic for the longest period. The study of terrain, its topography, the meteorological conditions, the snow patterns, the ice formation, the avalanche behaviour and some of the suggested clearing techniques and avalanche control measures form an essential part of a humble beginning to arrive at a reasonably workable solution.

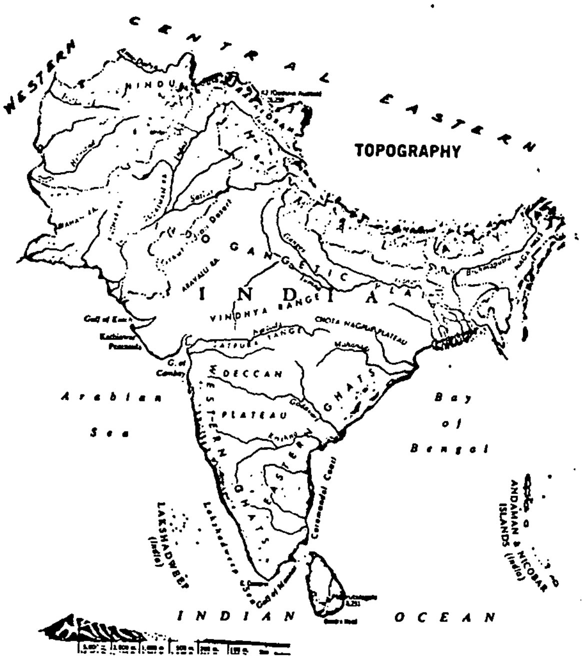

Figure 1. Map showing Western, Central and Eastern Hamalayas.

Topography and Meteorological Feature

The Indian Himalayas can be divided into three regions (Fig. 1).

(a) Western Himalayas
(b) Central Himalayas
(c) Eastern Himalayas.

Each zone of these Himalayas, which covers approximately 260,000 km^2, has different topography and meteorological conditions. The mountains are steep and the altitudes are high. The highest peak is located in the Indian Himalayas, which shows the type of altitude which one has to face. The vegetation and soil conditions in each region are different, depending upon the soil and the precipitation behaviour of snow.

Western Himalayas

The Western Himalayas have an average altitude between 3,000 to 5,500 m through which the roads and pedestrian tracks have to pass. The tree line ends approximately at 3,000 m. Between 3,000 and 4,000 m the growth of grass at places is quite common. Beyond 4,000 m the hills are almost barren and devoid of vegetation with rocks and steep slopes. The snowfall is maximum between 3,700 and 5,000 m. The steep mountain faces offer an ideal triggering surface for the avalanches. The worst area known so far, from the avalanche point of view, may be the Zojila sector in J&K State. The minimum air temperature in the snowbound areas ranges from +20° to -30°C. There is a considerable variation between day and night temperature which causes fast changes in the temperature gradient of the snowpack. Wind activity is very severe, and winds with as much as 130 km per hour velocity have been recorded at the height of 4,000 m. The steep and the narrow valleys further aggravate the high wind activity along with the tremendous problem of snowdrift. The temperature gradient on the southern slopes of the hills is the lowest and it has been seen that melt rate of snow on south-eastern slopes is maximum. Northern slopes are the coldest. The snowfall in this zone starts as early as November, carries on til May-June, and is maximum in this region.

Western Himalayas have a maximum snowbound area and the population in the snow-belt is approximately 8,000,000. The road network is both of tarmac and water bound macadam. The population is widespread in different green belts and their existence depends upon keeping the road communication open for the maximum period. In this region, there are two major roads, i.e. Jammu-Srinagar-Leh and Chandigarh-Manali-Leh. These two roads are the lifeline for the people living in various valleys. These roads have to pass through a number of avalanche-prone areas besides skirting the high-altitude mountains where cold regions problems affecting roads are at a maximum.

MAXIMUM AND MINIMUM TEMPERATURES °C

(Trail site an observatory in the Western Himalayas)
Height: 2,410 m

	73-74		74-75		75-76		76-77	
Month	Max	Min	Max	Min	Max	Min	Max	Min
Nov	+19	-5	-	-	-	-	+18	-7
Dec	+10	-12.5	+2	-18	+7	-16	+12	-17
Jan	+08	-14	+2	-18	+5	-18	+03	-18
Feb	+12.5	-18.5	+7	-18	+6	-20	+09	-14
Mar	+12.5	-06.5	+12	-11	+10	-11	+12	-11
Apr	+17.5	-02.9	+15	-05	-	-	+06.5	+03

MONTHLY AVERAGE DIURNAL VARIATION, °C

Month	73-74	74-75	75-76
Nov	-	-	-
Dec	10.4	6	9.6
Jan	10.2	6.3	9.6
Feb	10.7	11.3	9.5
Mar	08.2	10.5	9.6
Apr	13.3	7.4	-

Central Himalayas

The Central Himalayas have an average altitude between 3,000 and 5,000 m through which the road and pedestrian tracks have to pass. The snowfall regions are above 3,000 m and the high-intensity snowfall is between 3,000 and 6,000 m. In this region the soil is loose with steep mountain slopes covered with loose rocks. The tree line in this region ends at about 3,800 m and the climate is such that enough moisture is available for adequate grass and bush growth up to 4,000 m. However, in depth, the mountains are dry with very little rainfall. Maximum snowfall is experienced between December and March and the intensity of snowfall is not very high. The pattern of snowfall is the same as in the Western Himalayas. Minimum temperatures in this region vary from +30° to -20°C, and this helps in melting the snowpack faster. The high temperature gives rise to wet snow conditions. The wind activity is not very severe, though winds as high as 100 km per hour velocity have been recorded in certain areas through which the roads are passing. The easternly and southernly aspects experience high temperatures and more rainfall and have more trees. However, the northerly aspects have adequate vege-tation. Beyond certain regions, due to high day and night temperature difference, loose rocky faces create landslide problems. The avalanches in this zone invariably are accompanied by large amounts of loose rock and soil.

This region is more densely populated than the Western and Eastern Himalayas. The population in this region is approximately 9,000,000. It has a major road network connecting Spiti and Joshimata Valleys of Himachal-Pradesh and Uttar Pradesh with the plains.

MAXIMUM AND MINIMUM TEMPERATURE °C

(Trial site an observatory in the Central Himalayas)
Height: 3,000 m

	70-71		71-72		72-73	
Month	Max	Min	Max	Min	Max	Min
Nov	-7	-	+17.8	+02.2	-	-
Dec	+17	-03	+17.2	-01.1	+11	-02
Jan	+15	-05	+13.3	-02.8	+14	-06
Feb	+17.5	-07.5	+13.3	-10.0	+15	-06
Mar	+24.5	-04.0	+17.1	-02.2	+15	-06
Apr	+21.0	+09.0	+18.9	-09.0	-28.9	+04

Eastern Himalayas

The Eastern Himalayas are greener and the tree line is much higher. The climatic conditions are entirely different from those of the Western or Central Himalayas. The tree line at places is as high as 3,800 m. Up to 4,800 m height adequate bush undergrowth has been seen which grows as high as 2 m with thick branches interwoven to form a network. Thus bushy growth is an ideal snow trap and acts as an avalanche control measure. Temperatures are not very low and vary between +35° and -10°C. This part of the Himalayas is very humid and experiences heavier rainfall and low wind activity. The population is about 800,000, which is widely spread out. The movements are normally based on mules and foot columns passing through snowbound regions but not through much of the avalanche prone areas. The hidden resources in the rich soil of the Eastern Himalayas are yet to be tapped and the good road communication facilties have to be established to keep pace with the development and increase of population.

Snow Conditions

The Himalayas are the world's most formidable snow-covered mountains. The snowfall pattern from the Western Himalayas to the Eastern Himalayas is quite different and varied. In the Western Himalayas the snowfall starts in November and continues up to May. The snowfall is frequent and of high intensity. The temperatures are reasonably high after the snow fall as compared to the European Alps. On the average about 20 metres or above of snowfall is experienced each winter. The avalanche activity is basically due to dry snow conditions in the early winter and wet snow conditions in the late winter. In the Eastern Himalayas, the snowfall is followed by more clear days and the intensity of snowfall is also lower, varying from 2 cm/hr to 8 cm/hr. The high temperature melts the snow much faster and the snow slides are basically of wet snow.

In the entire Himalayas, short snowfalls of high intensity, followed by number of clear days, are very predominant. This factor makes the snow conditions quite wet and it has been noticed that this has a unique influence on the cycle of metamorphism.

TOTAL SNOW FALL AT SITE A - 2410 m HEIGHT
(WESTERN HIMALAYAS)

Month	1973-74	74-75	75-76	76-77
Dec	49	375	133	169
Jan	297	325	249	439
Feb	334	362	429	109
Mar	155	258	283	Nil
Apr	8	40	60	Nil
Total Snowfall	843	1360	1154	717

Cycle of Metamorphism

Due to the high temperatures prevailing immediately after the snowfall and there being a wide difference between day and night temperatures, the cycle of metamorphism is quite enhanced. In all areas a unique phenomenon was noticed that in most places avalanches occur at the round and square grain stages of snow crystals. This, when compared with the European Alps avalanche conditions, is quite different. In the Alps, the avalanches basically occur at the end of constructive metamorphism and with the snow crystals having reached depth hoar formations. In the Himalayas at a very few places depth hoar crystals have been noticed. Due to the high temperature pattern during the day and fast melting of the grains, the lubrication between crystals creates an ideal situation at the beginning of constructive metamorphism for avalanche occurrence. This melting of snow followed by a drop in temperature at night creates another major problem of refreezing the water on the road surfaces. The thin layer of ice on the roads causes disruption of the traffic. During late winter, i.e. March-April, the high temperature takes the cycle of metamorphism from destructive to melt phase, and with adequate liquid layers present between the crystals, the lubrication is increased and normally melted snow avalanches occur accompanied with tremendous amounts of rocks and earth.

The absence of depth hoar crystals, in the cycle of snow metamorphism, appears to be a unique phenomenon. A number of trials have shown that as the Eastern Himalayas are approached, the cycle of metamorphism tends to shorten by directly changing from destructive metamorphism. However, the appearance of round grain crystals at the end of destructive metamorphism and at the beginning of constructive or melt metamorphism is very predominantly observed. Further, most of the avalanches in the Himalayas are at the round grain stage of snow crystals, followed by wet avalanches. This phenomenon being a unique one in the Himalayas requires a laboratory analysis of the snow temperature patterns and their effect on the snow metamorphism.

Wind

The wind pattern observed in the Himalayas shows that immediately after the snowfall there is a lot of wind activity and the night temperature drops considerably, whereas during the day the strong radiation of the sun increases the temperature. In the early winter, i.e. November-December, an enormous amount of snowdrift occurs and most of avalanche activity is of the dry snow type. During midwinter, i.e. January-February, the wind activities further increase, increasing the snow drift, and this combined with heavy accummulation in the formation zones of the avalanches creates dry slab avalanches.

The high velocity winds at the heights above 5,500 m have been noticed to be of the order of 150 km/hr and above. This blows the snow away and leaves the mountain faces barren on certain aspects whereas on the other aspects a thick snow blanket exists and keeps on accummulating over a long period. This gives a base for the formation of snow beds. The snow beds of various layers have been noticed and the thickness of layer which is accumulated each season is predominant. Heavy wind velocity and drifting of snow is another problem which has been studied in the Himalayas. In the Western Himalayas, the winds of the order of 130 km per hour have been noticed and interesting results have been seen. At a trial site:

> It was noticied that while a snow blower was clearing the road surfaces and giving a cut of 1 m deep, the drift snow was so strong, that, by the time the blower reached 500 metres the accumulation of the snow due to drift on cleared road surface was again as high as 0.7 m. This shows the clearance effort which is required during the high velocity winds.

The chill factor at the high altitude along with the drift snow further complicates the snow clearing operation on the roads. During the night the temperature drops and it solidifies the snow layer which is left overnight after mechanical snow removal. This snow layer creates icing problems in large stretches. Various experiments conducted on de-icing on road surfaces are dealt with separately in this paper.

Avalanches

A unique phenomenon of avalanche occurrence that has been in the Himalayas is that most of the avalanches, particularly in the Western and Central Himalayas, come down more than once in a season. The most frequent average occurrence of avalanches is about 5 to 6 times in a season as compared to the avalanche occurrence in Europe which is generally once or twice in a season. From this, it is apparant that the avalanche engineer must plan for waves of avalanches while designing avalanche control structures for Himalayas. This not only affects the economics of avalanche control but also creates tremendous technical problems to be overcome in the construction of protective structures.

DE-ICING

The isothermal analysis of the Western Himalayas suggests that a large part remains at subzero temperatures even during the day time throughout the winter months. This, combined with snow precipitation caused by the low pressure systems induced by extra-tropical cyclones moving on comparatively southern latitudes, adds to the problems of icing on the roads, Further, overflow of water on to the road surface due to defective drainage systems and sudden low temperatures at night are responsible for the formation of thin layers of ice on the road surfaces. This ice formation on the road leads to the disruption of the traffic.

A trial was conducted on de-icing techniques to find a suitable one for Himalayan conditions. Some of the results obtained are given in the subsequent paragraphs. The common practices adopted for overcoming icing problems are melting by heat, use of abrasive materials such as stone chipping and sand on the iced surfaces for increasing sliding friction, and preventing of ice formations by the anti-icing capacity of certain chemicals.

The de-icing trials were carried out by using sodium chloride, calcium chloride and urea. A comparative study using the three salts mentioned above, along with coal dust, river sand and soil mixture gave startling results (see below).

Normal soil, river sand, or fine clay, duly graded and sprinkled on the snow or ice surface, increases heat absorption. Thus, the melting of ice takes place using the heat of radiation.

The seepage from drainage is the biggest source of water available for freezing at night. Rock salt, in rock form packed in gunny bags, showed appreciable results as an anti-icing agent when kept in the drains for slow mixing along with seepage water. It is interesting to note that this technique is very effective during early winter when the temperatures are slightly above 0°C. The use of rock salt is not only considered suitable in the Himalayas, but may be of great use wherever the temperature pattern and seepage problems from overflowing drains exists. The use of rock salt has advantages as the replacement may not be required for a number of nights. It was noticed during trials that by this technique most of the ice melted during the first night. No ice formation was observed during the second night. However, during the 3rd and 4th night, the salt solution became weak and thin layers of ice formations were observed on the outer edges of the road. This shows that charging of drains with 20 to 40 kg rock salt packed in bags may be required every 3rd night depending upon the quantity of water seepage and weather conditions.

During the trials with the chemicals on de-icing, it was further observed that in the initial stages, as the temperature fell below 0°C, that the decrease in percentage melt was statistically significant at the 95% level in most of the cases, even at a reduction of 1°C of atmospheric temperature. The table given below shows the percentage melt at various durations and temperatures in respect of the three chemicals.

Effectiveness of Chemicals used for Deicing

It has been observed that, out of the samples studied, sodium chloride was the most effective. The percentage melt generally attains a higher average, though the desired rate of 60% could not be achieved when the thickness of the ice samples exceeded 1 cm. The percentage melt rate in respect calcium chloride follows a path similar to that of sodium chloride, but the average melt percentage is slightly low at all temperatures. It was observed that for calcium chloride, the melt rate during initial 30 minutes was faster than the other chemicals by 1% to 3% but shows abrupt fall off thereafter. This can be attributed to the additional heat produced by the exothermic reaction of calcium-chloride. In the case of urea, the spread rate is generally greater than sodium chloride and calcium chloride but the average percentage melt is significantly lower.

TABLE A

Sodium Chloride

Thickness of ice slab = 2 cm
Rate of spread = 500 g/m^2
Wind = calm

Temp/min	10	20	30	40	50	60	70	80	90
-2	12	23	33	42	49	53	56	58	60
-3	11	21	31	39	45	50	54	55	56
-5	10	20	28	34	42	47	50	52	54

Calcium Chloride

Thickness of ice slab = 2 cm
Rate of spread = 500 g/m^2
Wind = calm

Temp/minute									
-2	13	24	34	42	48	52	54	55	56
-3	12	22	31	38	44	48	52	53	54
-15	11	20	29	37	42	47	50	52	54

Urea

Thickness of ice slab = 2 cm
Rate of spread = 800 g/m^2
Wind = calm

Temp/minute									
-2	12	22	31	41	46	49	51	53	54
-3	11	21	30	38	43	48	51	52	52
-5	10	19	28	34	40	44	47	49	50

Snow and Avalanche Control Technology

Ice, snow and avalanche research in India is still in its infancy. This field was neglected due to socio-economical reasons. However, the availability of minerals, the development of a tourism network and vast settlement problems of the past few years have increased its importance.

Snow Physics

In India, the winter lasts for a period of 3 to 4 months and severe winter conditions prevail only between December to February. During this period the temperature rises at times. The formation of snow crystals in the atmosphere under such conditions is mostly wet snow and the life of star-like crystals is short-lived. The temperature pattern on the ground shows high diurnal variations and it has been observed that the cycle of metamorphism, starting from fresh snow to felt-like grains and then up to melt grains (in the order of ET* metamorphism, TG metamorphism and MF metamorphism), does not go in a sequence. The snow crystals in the Indian Himalayas enter the phase of TG metamorphism. This is due to the proximity to the freezing level over a longer period. The crystals reach the round grain stage within a very short time and further change to irregular grains within a period of 6 to 7 days during low atmospheric temperatures. This irregular grain crystal structure directly goes into the melt phase and the cup crystal or depth hoar phase is left out. For accurate prediction of avalanches in India the norms used by foreign scientists have to be modified since those are based basically on cup crystal or depth hoar formation.

Snow Mechanics

Swiss guidelines for avalanche control structures are mainly based on the deformation characteristics of dry snow which is prevalent in that country. However, the Indian snow being semi-dry and wet, the same deformation characteristics may not be applicable. Using the Swiss guidelines, we have tried avalanche control structures, but these have been only 70% effective in Western Himalayas. The studies to find the guidelines for Indian snow conditions are in progress but no final solution has so far been found.

Avalanches

Identifying avalanches according to the avalanche classification evolved by de Quervain is being followed in India and it has been noticed that the results are quite satisfactory. The Swiss method of zoning of avalanches is quite accurate and informative but time-consuming. In India we find that this method can only be applied where major settlements are being planned. The French method of avalanche mapping is found to be more useful, i.e. use of aerial photographs, but its accuracy appears under Indian conditions to be lower than that of the Swiss method.

Avalanche Control

For designing the supporting structures for the control of avalanches, Swiss guidelines specify two types of loading. In the first type of loading, the snow depth is at a maximum but the density is moderate; in the second type of loading, density is at a maximum and the snow depth is moderate. Under Swiss winter conditions, the designing is based on one of these conditions depending upon location and the purpose of avalanche control. In India it has been seen that both these conditions of loading are experienced at the same time at most places. Further the average density of 270 kg/m^3 as used in Swiss guidelines is considered much too low for Indian conditions. In India, design at a value of average density greater than 350 kg/m^3 gives better results; however, this figure is not yet final and absolute for Indian conditions. Since the density is higher and both loadings are prevalent at the same time, we have to go in for massive design of supporting structures which involves very high expenditures.

The height of avalanche control structures has to be designed for 4 to 6 waves of avalanches unlike in Swiss practice where only 1 to 2 waves are anticipated. This makes the structures very massive. Further, the avalanche control structures have to be erected almost always above 4,000 m which adds to the construction cost and high altitude engineering problems.

Economics of Control Structures

Economics of snow and ice control is the biggest hurdle for a snow engineer. How to keep total costs low and how to find which control technique can be the cheapest and the best suited are the most difficult parts of the design. India, with its vast and deep Himalayas, has hundreds of kilometers of roads and tracks passing through snow, avalanche and ice prone areas, offering a challenge for snow control engineers. This is further aggravated by the fact that a developing country is always short of funds. The weather pattern, the difficult Himalayan terrain conditions, and lack of technical norms suitable for Indian snow and ice conditions make it a still bigger task. Some of the factors which affect the snow control measures in Indian Himalayas are enumerated below.

(1) Design problems. Snow conditions being semi-dry, density of snow being high and with annual avalanche occurrence being above 4, control structures have to be massive and costly.

(2) Construction problems. The construction of snow and ice control structures has to be mostly above 5,500 m. This adds high altitudes construction problems and increases the cost further.

(3) Construction time. The construction time available is short due to the limited number of clear days available. Due to extreme cold conditions, the number of working hours available daily is also very limited. The working time is hardly 6 hours in a day.

(4) Store carriage. The structures have to be fabricated at a great distance from the site. The carriage in vehicles over long distances of roads adds to the cost. At the site the prefabricated control structures have to be manually hauled up for hundreds of metres where the erection is to be done. This is a slow and laborious process and a big time consuming factor.

(5) Labour. At most of the places the skilled and unskilled labour has to be imported from the plains or the towns which may be hundreds of kilometers away. The labour camps have to be in safe places and at much lower altitudes. The movement of labour to or from the work site takes a major share of the time. The energies are half-consumed in travelling only. The labour cost is as high as 60% to 70% of the total budget of construction.

(6) High altitude living conditions. The living in high altitude areas for long periods without facilities discourages the best tradesmen. Thus at times one has to depend upon second-rate tradesmen which affects the construction speed and quality.

Having known the problems which a snow engineer has to face, his task of correct selection of sites and the type of control measures and technology to be followed becomes very difficult. The most difficult question to answer is whether the avalanche control should be at the formation zone, which is high and far above the tree line, or in the avalanche

* MF - melt phase metamorphism, ET - equitemperature metamorphism, TG - thermal gradient metamorphism

path or run out zone. Of course, the requirement for which the avalanche and snow control is envisaged holds an upper hand.

At the formation zone, the cost of erecting snow bridges and snow fences is extremely high. However, at times, the site conditions through which the roads are passing force the use of this control technique.

In the avalanche path it has been seen that retaining dams made of earth with a combination of earthen mounds are the most economical. Some of the avalanches which have been controlled by retaining dams/structures have shown encouraging results and it appears that the use of local resources, i.e. earth, rock and timber, is the most economical method. However, the designs have to be massive.

At the run out zone, diversionary and retarding earthern dams/mounds have proved to be the most useful and best suited from the cost point of view.

The use of galleries and tunnels is the most expensive method of avalanche control. However, due to the road location and type of avalanches which have to be controlled, such structures have proved very successful. This has proved very economical in the long run and ensures that the road is open for traffic for the longest period.

Drift control structures have not been tried out much in India. However, the cost of these is considered quite high and one has to use them only sparingly.

The de-icing and anti-icing techniques have their own logistical and storage problems which make them unsuitable for long stretches of road. However, for short stretches the use of NaCl (sodium chloride) is considered to be most economical. The use of rock salt packed in gunny bags placed in water seepage areas, drains, and culverts proved to be very successful and economical. This may help the de-icing problems all over the world where similar situations exists.

Considering the different weather patterns and varied terrain conditions from the Western to Eastern Himalayas, it is imperative from a cost point of view to restrict the use of avalanche control structures to selected places only. However, avalanche forecasting to regulate the movement in isolated areas is considered to be most economical. The avalanche forecasting in the Western Himalayas has proved considerably successful. This has reduced the avalanche casualties in that area to a great extent. It appears that for mass usage the most economical method may be for the avalanche forecast technology to cover the complete Himalayas. The following chart shows the lives which have been saved due to timely warning of avalanches.

No avalanche forecast		Avalanche forecasts issued		
	Before '74	'74-'75 Winter	'75-'76 Winter	'76-'77 Winter
Avalanche deaths in number-Western Himalayas	Over 100	73	32	14

Conclusion

The control of snow and ice on roads and communication facilities in the Indian Himalayas is a task of high importance. The vastness of the Himalayas and the varied climatic conditions in different regions add to this challenge. The technical norms of Swiss snow conditions cannot be applied to Indian snow conditions. The temperature pattern affects the metamorphism of snow crystals much more quickly and almost all avalanches are triggered at the round grain or square grain crystal stage, unlike those in the Alps where depth hoar is responsible. This poses a problem because norms which have been worked out for Swiss snow conditions cannot be applied to Indian conditions. The metamorphism cycle from the destructive phase directly changes to the melt phase in India, giving rise to semi-dry or wet snow avalanches. Nowhere in the world has the density of wet flowing snow avalanches been worked out and the values of density for Indian conditions have to be much higher than normal for satisfactory results. This problem, when combined with the number of waves of avalanches for which control structure are designed, adds to the massiveness of design, which in turn adds to the cost. Whatever the method of control of snow and ice, the economics and the engineering requirements have to be well balanced.